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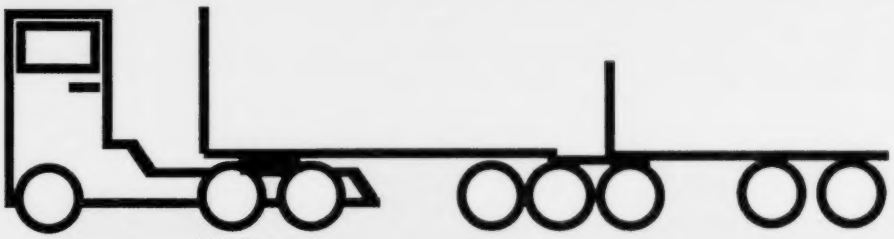
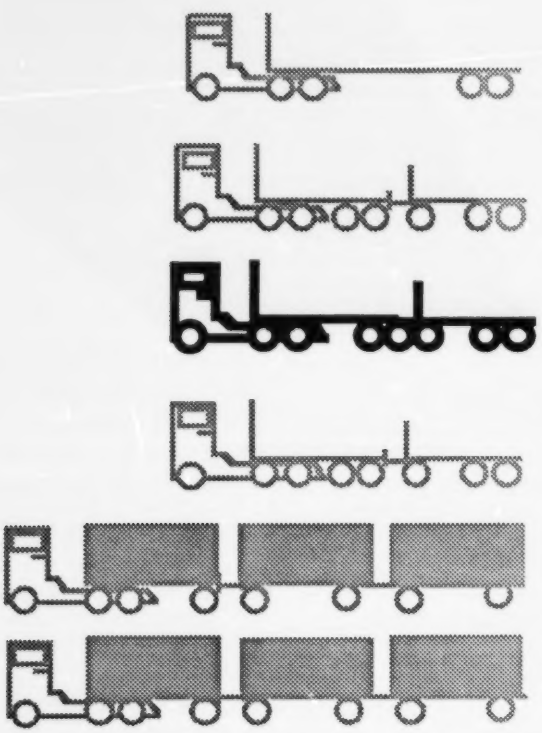
Demonstration of Baseline Vehicle Performance: B-Train Double





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Demonstration of Baseline Vehicle Performance: B-Train Double

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Prepared for:
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Abstract:
An B-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

An B-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated a base-line vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a B-train double trailer combination baseline vehicle. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and a B-train flatbed double trailer combination with a centre triple axle and rear tandem axle. The combination is typical of equipment used in Central Canada in heavy-haul applications.

The equipment for these tests was obtained from Transport Canada by the study. No modifications were made to the trailers except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected [11].

The trailers were manufactured by Pullman Trailmobile Canada in February 1980 and bore the serial number 2.80.1110.1028.002. Both trailers had a nominal bed length of 7.92 m (26 ft) and a nominal width of 2.44 m (96 in). The lead trailer was provided with a triple-axle unit with an axle spacing of 1.52 m (60 in) and a Reyco six-spring suspension system with torque rods and equalizers. It had a fifth wheel mounted above the rear axle of the triple-axle unit. The tandem-axle rear trailer had an axle spacing of 1.79 m (70.5 in) and a Reyco four-spring suspension system with torque rods and equalizers. On both trailers the spring centre spacing was 0.96 m (38 in), the nominal track width was 2.44 m, and the axles were rated at 9616 kg (21 155 lb). The combination had an overall length of 22.1 m (72.5 ft).

The trailers and dollies were fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 600 km (370 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 26 155 kg (57 540 lb). Concrete blocks were used to obtain a loaded weight of 52 764 kg (116 080 lb). Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 650	10 230	4 991	10 980
2	3 996	8 790	6 082	13 380
3	3 500	7 700	5 723	12 590
4	3 386	7 450	7 864	17 300
5	2 918	6 420	7 827	17 220
6	2 664	5 860	7 232	15 910
7	3 077	6 770	7 536	16 580
8	1 964	4 320	5 509	12 120
Total	26 155	57 540	52 764	116 080

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was nearly attained, with the exception of the tractor drive axles and the last axle of the combination. Both trailers were loaded in the same fashion, consistent with normal practice. The legal gross weight of the vehicle tested is 56 600 kg (124 560 lb) in Quebec and 60 500 kg (133 100 lb) in Ontario, and would be about 52 000 kg (114 400 lb) where permitted in the prairie provinces.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.37 m (14.7 in) below the top of the floor. The centre of gravity height was estimated as 0.22 m (8.5 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger attachments were installed on the trailers.
3/ Outriggers were installed on the trailers.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer beds to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailers.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 600 km (370 mi).
14/ Articulation angle between the tractor and lead trailer was calibrated.
15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailers for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the two trailers were mounted in boxes placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	20.839°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Trailer 1 lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
19	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
20	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
21	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
22	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi
23	Brake pressure, axle 8 right	Celesco PLC-200G	106.79 psi
24	Spare		
25	Spare		
26	Trailer 2 articulation angle	Spectrol 8409 potentiometer	22.8°
27	Trailer 2 lateral acceleration	Columbia SA-107 accelerometer	0.980 g
28	Trailer 2 roll angle	Humphrey VM02-0128-1 vertical gyro	8.91°
29	Trailer 2 outrigger touchdown	Strain gauge bridge	1.0 V

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown in Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4. After averaging for both directions and correcting for differences in axle track width, the offtracking of 1.65 m (5.41 ft), shown in Figure 4, became 1.69 m (5.54 ft).

Table 3/ Offtracking

Axle No.	Track Width (m)	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.55	27.58	0.03	27.57	27.56	-0.04
2	2.37	27.26	27.32	0.06	27.29	27.21	-0.29
3	2.37	27.22	27.35	0.13	27.29	27.21	-0.29
4	2.37	26.41	26.55	0.14	26.48	26.07	-1.57
5	2.37	26.32	26.47	0.15	26.39	26.02	-1.42
6	2.37	26.34	26.45	0.11	26.40	26.07	-1.27
7	2.37	25.81	25.91	0.10	25.86	25.45	-1.61
8	2.37	25.76	25.86	0.10	25.81	25.45	-1.41

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft)

radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was 0.90 m (2.95 ft). It was out of the exit lane for a distance of 18.00 m (59.0 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was 1.55 m (5.1 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. The vehicle easily made it through the channel.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. The trailers were fitted with a Kelsey-Hayes anti-lock braking system, which was inactive for these tests. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi). Pressure transducers were installed at all trailer and dolly axles.

The SAE J982a style test was performed. The results of this test, presented in Table 4, are the average of several tests each with a time resolution of 0.02 s. The application and release times this test

compare favourably with those obtained from tests conducted on other double combinations [13]. The speed is due to the clean plumbing between the trailers, and the anti-lock system requirements. An additional 6 to 10 m (20 to 30 ft) of hose and various couplings on a converter dolly show the A- or C-train brake timings significantly.

A typical time history response of application and release for the full triple is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.04	0.12	84.4
Axle 2	0.40	0.54	87.6
Axle 4	0.56	1.46	84.1
Axle 5	0.62	1.50	83.5
Axle 8	0.68	1.56	84.3

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1].

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The initial average brake application of about 276 kPa (40 psi) caused all braked wheels on the vehicle to lock. The tractor jackknifed to the right, but the driver steered to the left and

was able to hold the tractor heading at about 10°. The two trailers remained under control, with the lead trailer heading to the right as the tractor moved out of the lane in that direction. If the front axle brakes on the tractor had been used, it is probable the tractor would not have jackknifed at this speed. The tractor and trailers were both fitted with anti-lock brakes. If these had been used, the wheels would not have locked until a low speed and, again, the vehicle would have remained under control.

A summary of peak vehicle responses from the runs is shown in Figure 12, as a function of average treadle valve pressure. The limit of surface adhesion of about 0.16 g was reached before 193 kPa (28 psi), but tractor jackknife did not occur until a significantly greater pressure was applied. Jackknifes occurred to both right and left, and in each case, the driver eased off the treadle valve during the stop, so the data points are plotted at a lower pressure than used initially.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 20.0 m (65.6 ft) for the lane change to the left and return to the original lane, separated by 20 m (65.6 ft) in the left lane. The runs were made in accordance with the standard test procedure [1].

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration of all vehicle units increased with speed up to 54 km/h. The rear trailer had the highest rate of increase. The heading amplitude tended to decrease with speed for the tractor and first trailer and remained relatively constant for the second trailer. Data reveal that there was minor rear trailer oscillation when the vehicle returned to the original lane. As the speed increased, increased steer at the tractor was necessary to negotiate the course. This indicated tractor oversteer and is supported by the driver's comments that the vehicle tended to "push." At 54 km/h the rear trailer swung out of lane on the return to the original lane. A typical run at this speed is shown in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration for the two trailers is presented in Figure 15, as a function of tractor steer input period for the three test speeds. Each gain is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15 that rearward amplification increases with speed. It also increases rearward by trailer. Finally, it is also somewhat sensitive to steer period, reaching the highest value of about 1.70 at about 2 s at 94 km/h. The results show that, at highway speed, the B-train double is a moderately responsive vehicle. The reason for this is that its inherent stability is high. Stability and response of mechanical systems have an inverse relationship. High stability means low response to input and vice versa. Figure 16 shows the vehicle response from a typical run with a steer period of about 2 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a fast lane change, which is considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections.

The results from all runs are summarized in Figure 17. The peak-to-peak lateral acceleration, roll, and yaw (or heading) angles all show an increase as the limiting speed of 85 km/h was reached, at which point the rear trailer rolled over to the left with outrigger touchdown, slid about 1 m into the adjacent lane, swung back to the right, and rolled with a second outrigger touchdown on the right. Figure 18 shows such a run. The response was rather violent, but the entire vehicle would not have rolled over. Lateral acceleration and roll gains are also shown in Figure 17. The lateral acceleration gains at 63 and 84 km/h were consistent with those from the sinusoidal steer test. Lateral acceleration lag time for the first trailer tends to climb and stabilize, whereas trailer 2 tends to fall for the first response peak, due to the steer to the left, as shown in Figure 17. The rear trailer response lags 1.0 to 1.3 s behind the tractor. Therefore, once the driver initiates an input, the vehicle response will follow and there is little that the driver can do to modify it. This lag time is simply due to the number of articulation points and length of the vehicle and is considered to reduce the driver's control of the entire vehicle. The yaw overshoot of the trailer is shown in Figure 17, which clearly illustrates the rear trailer swing at the limiting speed and is partially as a result of roll states. In all cases, the second trailer reacted more violently than the lead trailer, with the exception that the lead trailer overshot the most.

Figure 19 shows the steer input and vehicle response from a typical run at 85 km/h. The yaw histories show signs of oversteer, and the roll histories for the first and second trailers show a roll response to the right after the vehicle has entered the exit lane, no doubt due to the preceding oversteer track.

4.9/ Normal Straight-Line Driving

The objective of this test was to attempt to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure [1].

As previously mentioned, the vehicle was quite responsive, but the slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in rear trailer sway that was hardly perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 1.49 g/° of RMS steer

input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and to examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 20. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. At the limiting speed of 63 km/h, a lateral acceleration of 0.49 g, the outriggers of both trailers touched down, as shown in Figure 21 and 22. As Figure 22 shows, roll angles increased with speed. Average steady-state articulation angles are shown in Figure 20. These decrease modestly with increase in lateral acceleration, and as a consequence, the offtracking decreases. The lateral force experienced by the tractor fifth wheel is shown in Figure 20, as a function of tractor lateral acceleration. This shows a gradient of 13.8 kN/g (3100 lb/g).

A tilt test was conducted on this vehicle as part of a separate test program [14]. The vehicle is shown on the tilt table in Figure 23. The high-side wheels of the rear trailer lifted at a tilt angle of 26.9°, after all corrections were made, which corresponds to a lateral acceleration of 0.51 g. This is in quite good agreement with the rear trailer's lateral acceleration at outrigger touchdown of 0.49 g. A full discussion of the tilt test is presented elsewhere [14].

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical, in both empty and loaded conditions. In both conditions, the centre of gravity was somewhat lower than normal, particularly for the loaded condition, because of the underslung outriggers.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. The short trailer wheelbase made it easy to manoeuvre in low-speed turns, though high driver effort was required in these and dynamic tests, as the trailer imposed significant forces on the tractor. The vehicle was nearly as responsive as a similar A-train [5].

6/ CONCLUSIONS

A B-train double trailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated a baseline vehicle and the representative test vehicle for similar configurations.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The articulation of this vehicle clearly contributed to the small space required to make turns.

The air brake system was relatively fast and well balanced, largely because the B-train has no converter dolly and because the particular vehicle was equipped with anti-lock brakes.

The lateral/directional stability of the vehicle was moderate, both empty on a low-friction surface and loaded on a high-friction surface. Stability was clearly deteriorating at the highway speed limit of 100 km/h. The roll stability was high previously because of the low trailer centre of gravity height. A higher centre of gravity would significantly reduce the roll threshold.

7/ REFERENCES

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[3] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-03, June 1986.

[4] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: C-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-05, June 1986.

[5] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Triple," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-06, June 1986.

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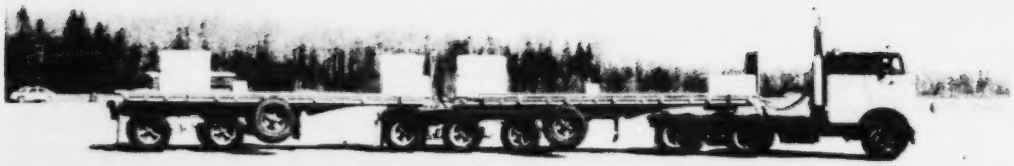


Figure 1/ B-Train Double, View of Vehicle

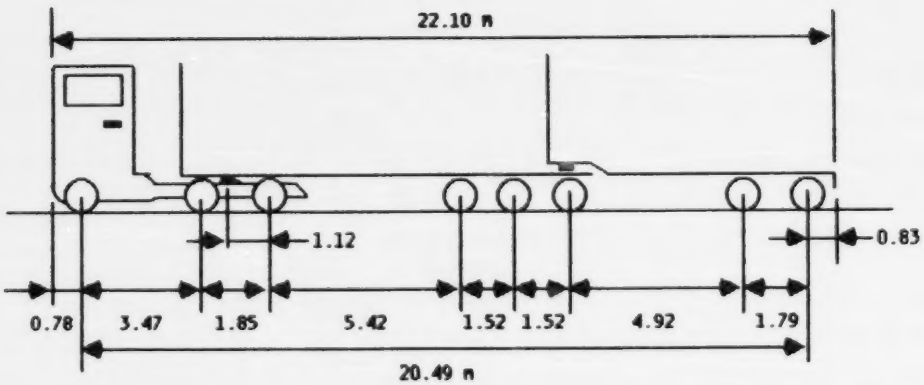


Figure 2/ B-Train Double, Vehicle Dimensions

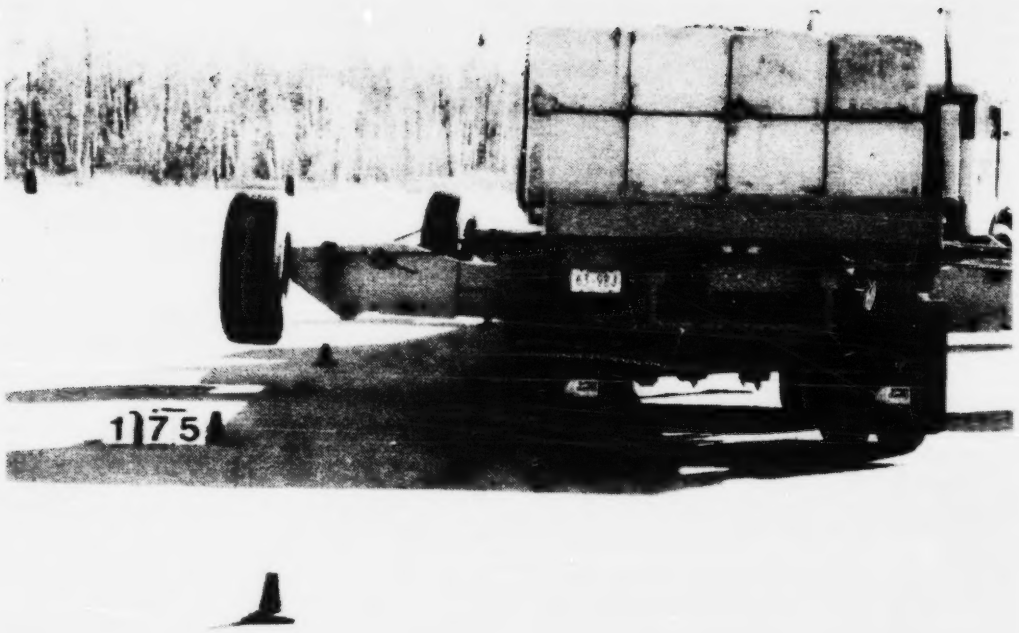


Figure 3/ B-Train Double,
Clockwise Offtracking

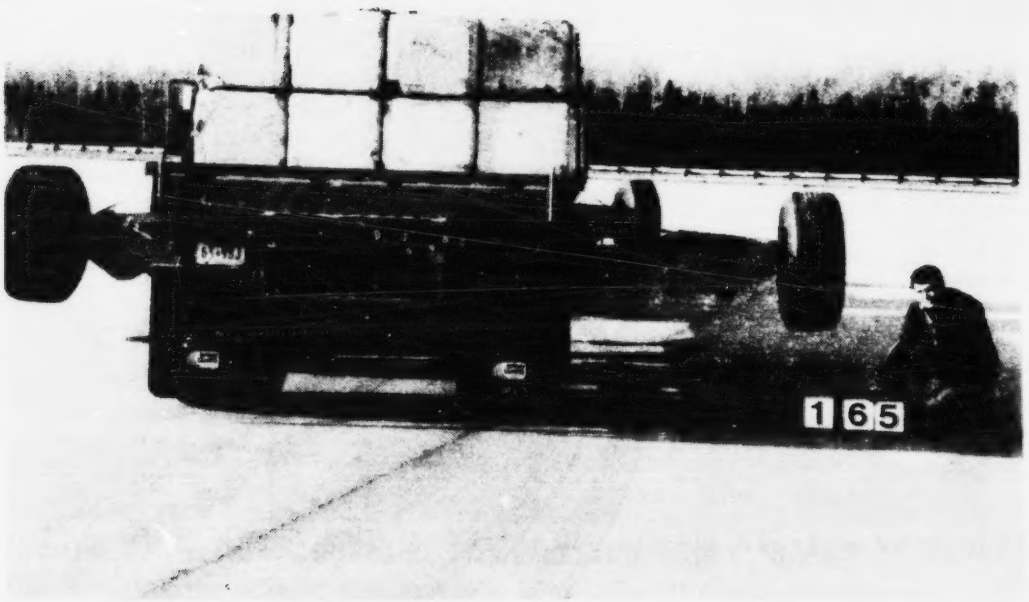
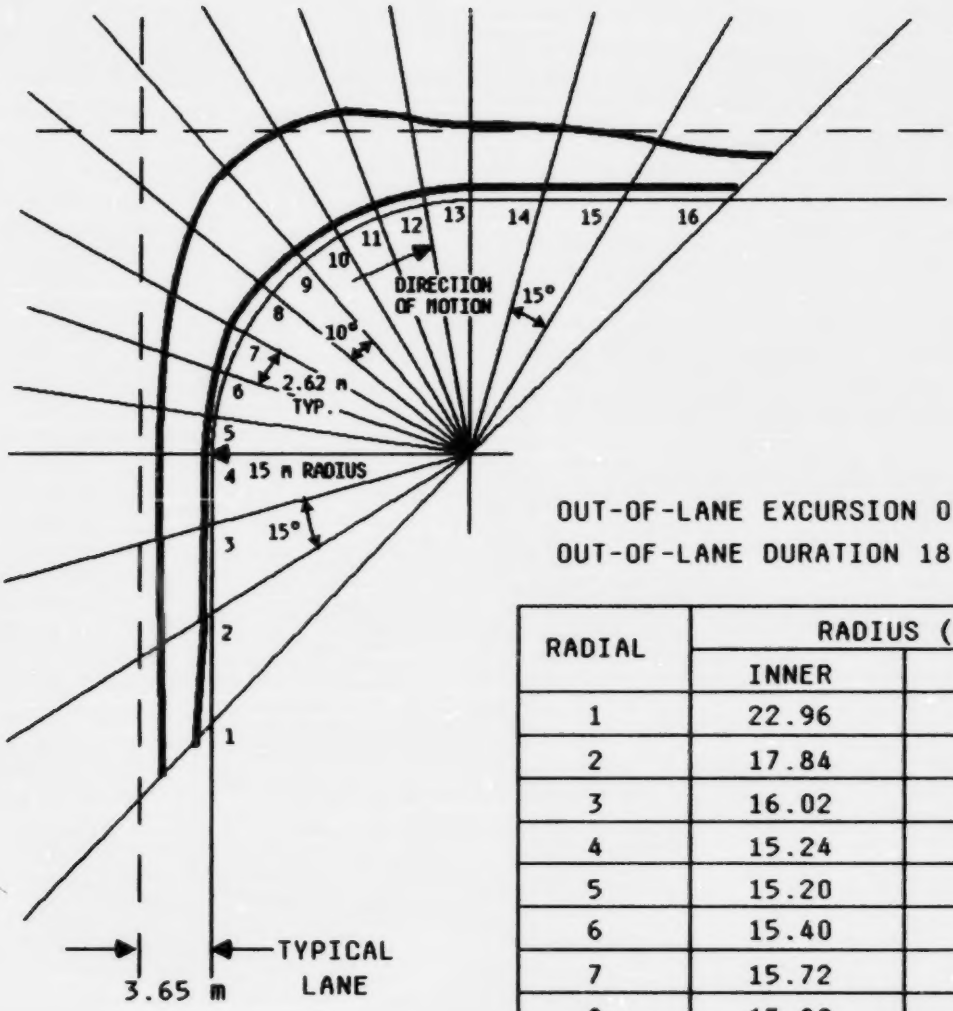


Figure 4/ B-Train Double,
Counter-Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 0.9 m

OUT-OF-LANE DURATION 18 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	22.96	25.36
2	17.84	20.58
3	16.02	18.46
4	15.24	17.76
5	15.20	18.04
6	15.40	18.70
7	15.72	19.69
8	15.80	20.62
9	15.64	21.65
10	15.40	21.71
11	15.26	21.15
12	15.25	19.82
13	15.36	19.13
14	16.13	19.85
15	17.95	20.91
16	21.69	24.55

Figure 5/ B-Train Double, Right-Hand Turn Swept Path

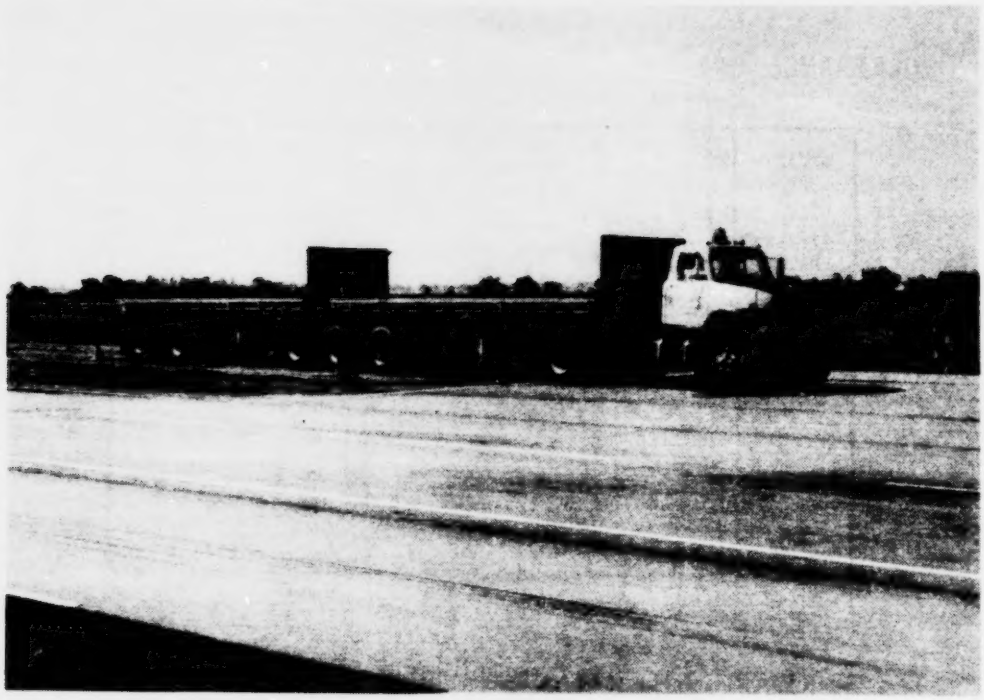
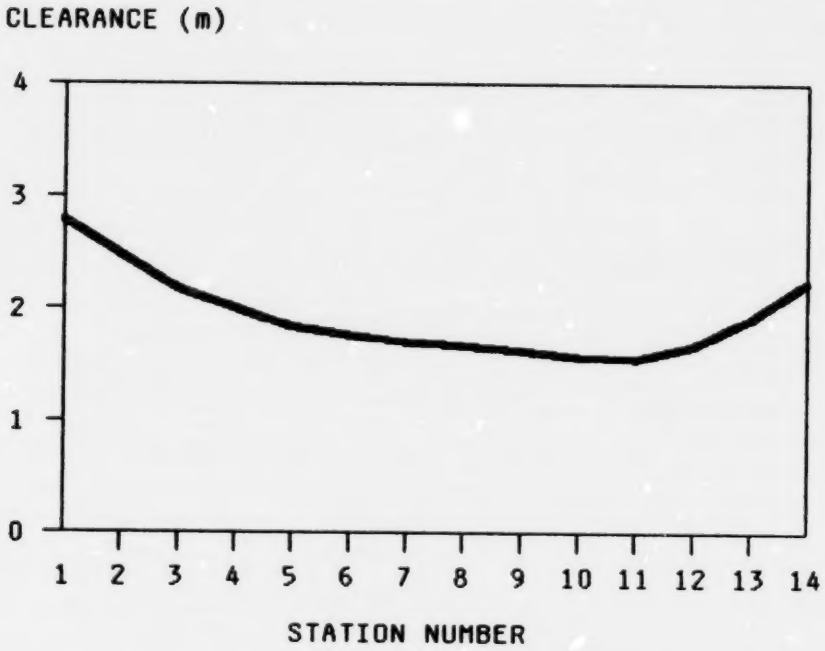


Figure 6/ B-Train Double, Right-Hand Turn

Figure 7/ B-Train Double, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.79
2	2.48
3	2.18
4	2.00
5	1.85
6	1.76
7	1.69
8	1.68
9	1.62
10	1.57
11	1.55 *(LOW)
12	1.68
13	1.91
14	2.25

Figure 8/ B-Train Double, Channelized Right-Turn Clearance from Inner Curb

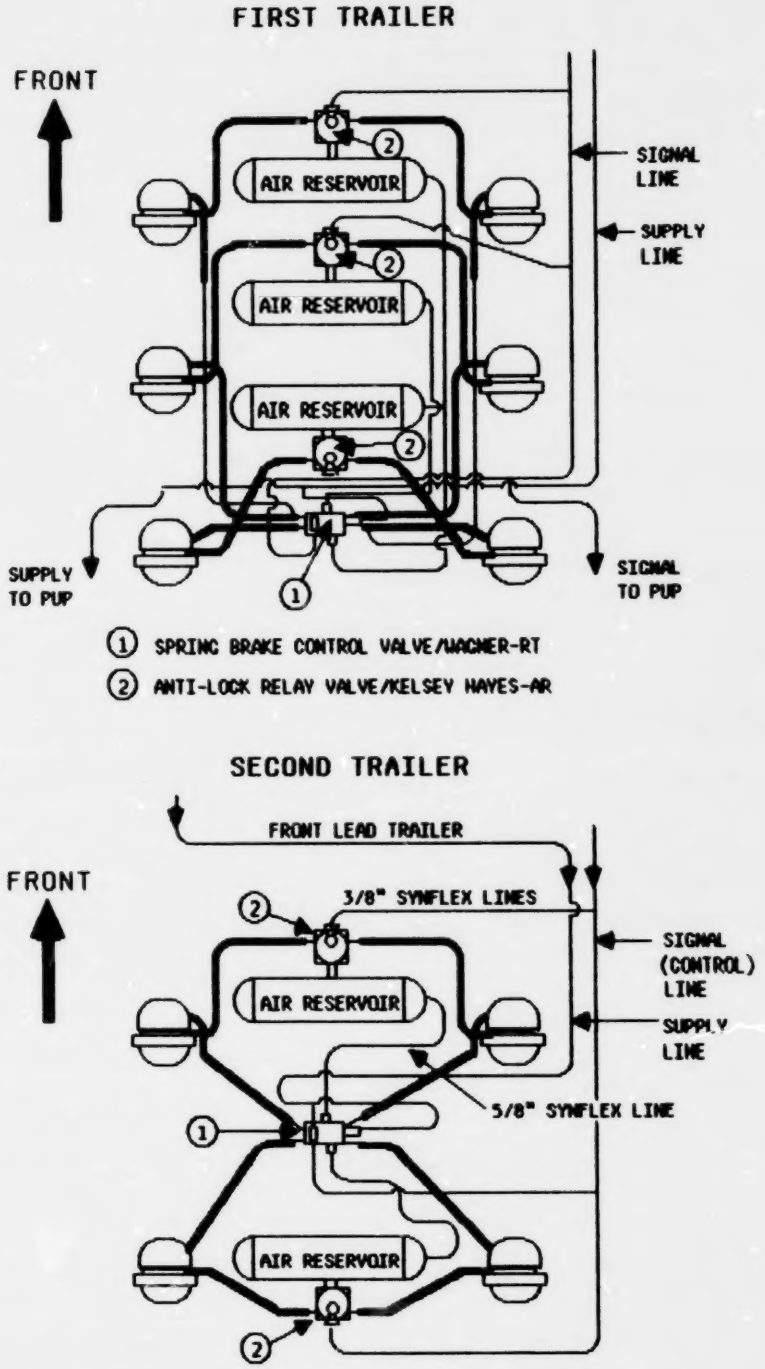


Figure 9/ B-Train Double,
Air Brake System Schematic

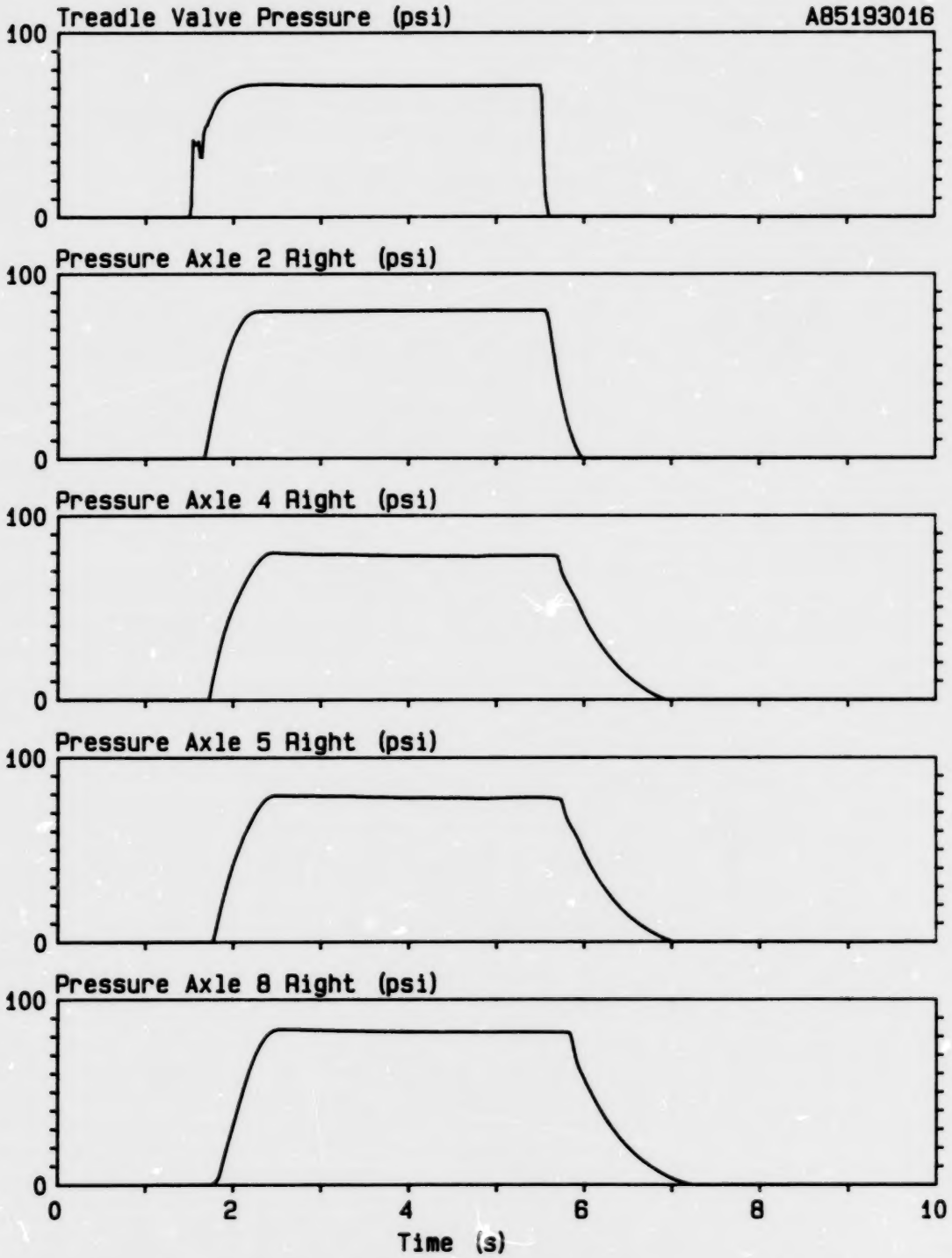


Figure 10/ B-Train Double,

Air Brake Application and Release

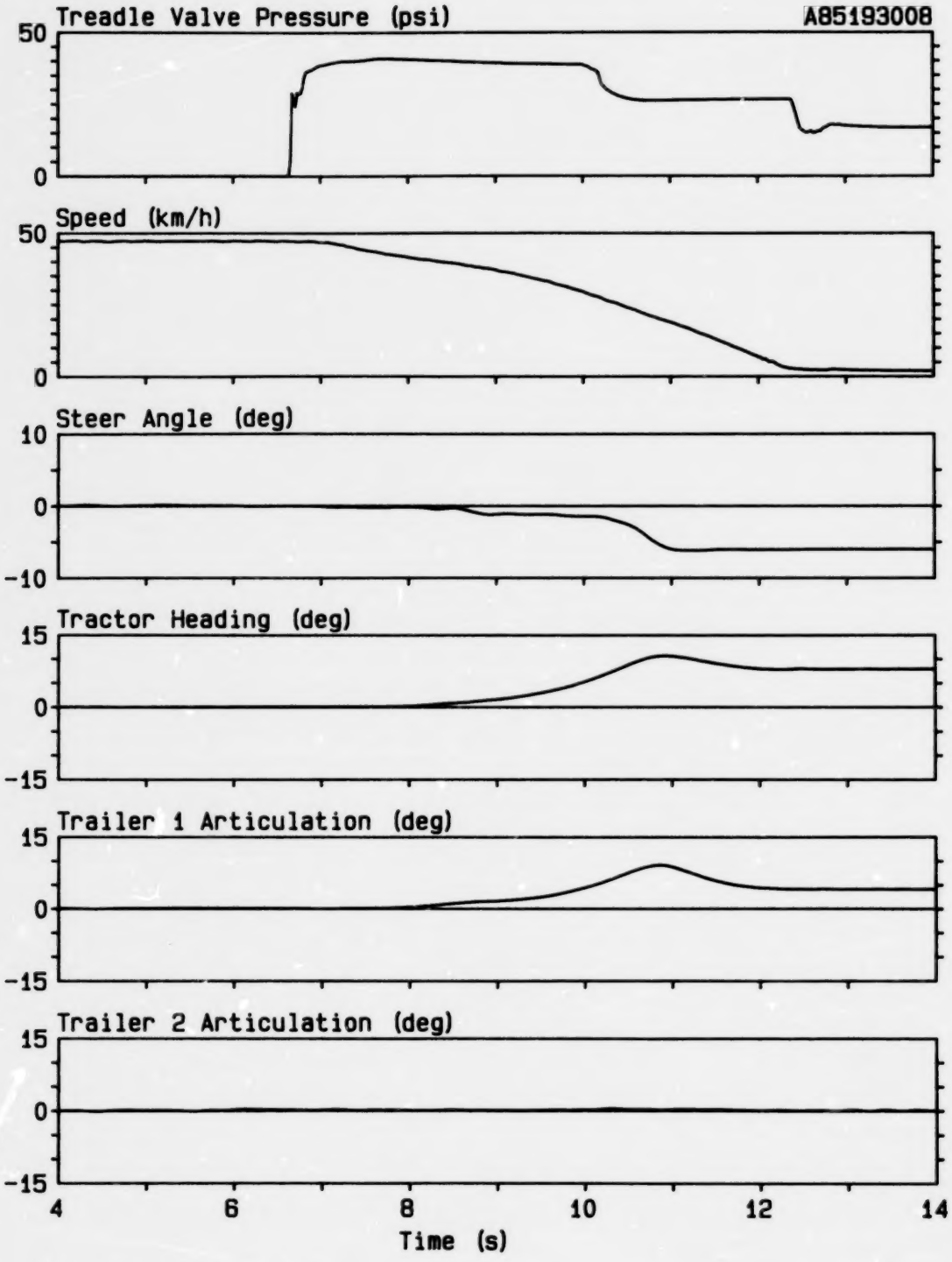


Figure 11/ B-Train Double,

Vehicle Response to Straight-Line Braking

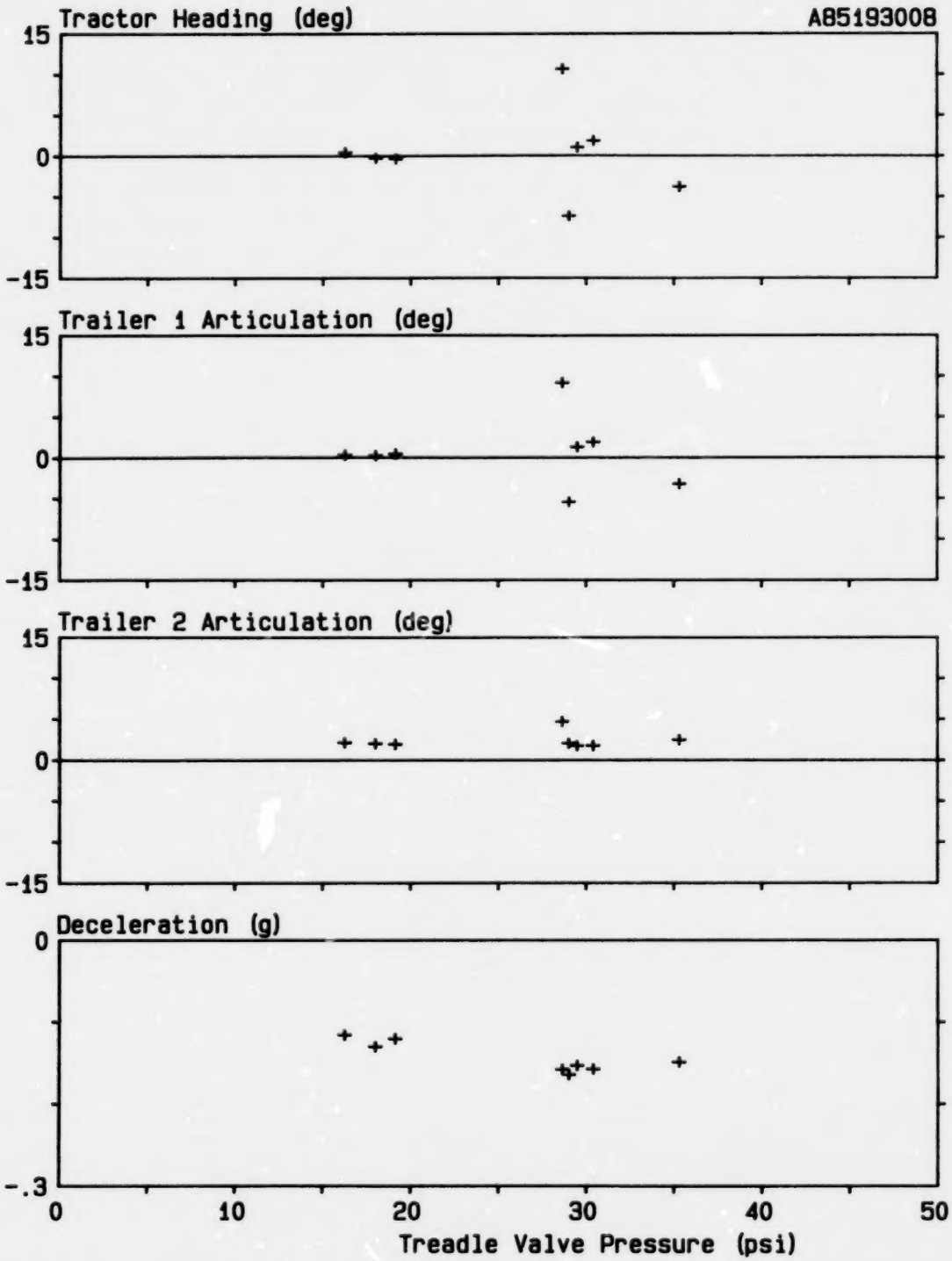


Figure 12/ B-Train Double, Straight-Line Braking Responses vs Treadle Valve Pressure

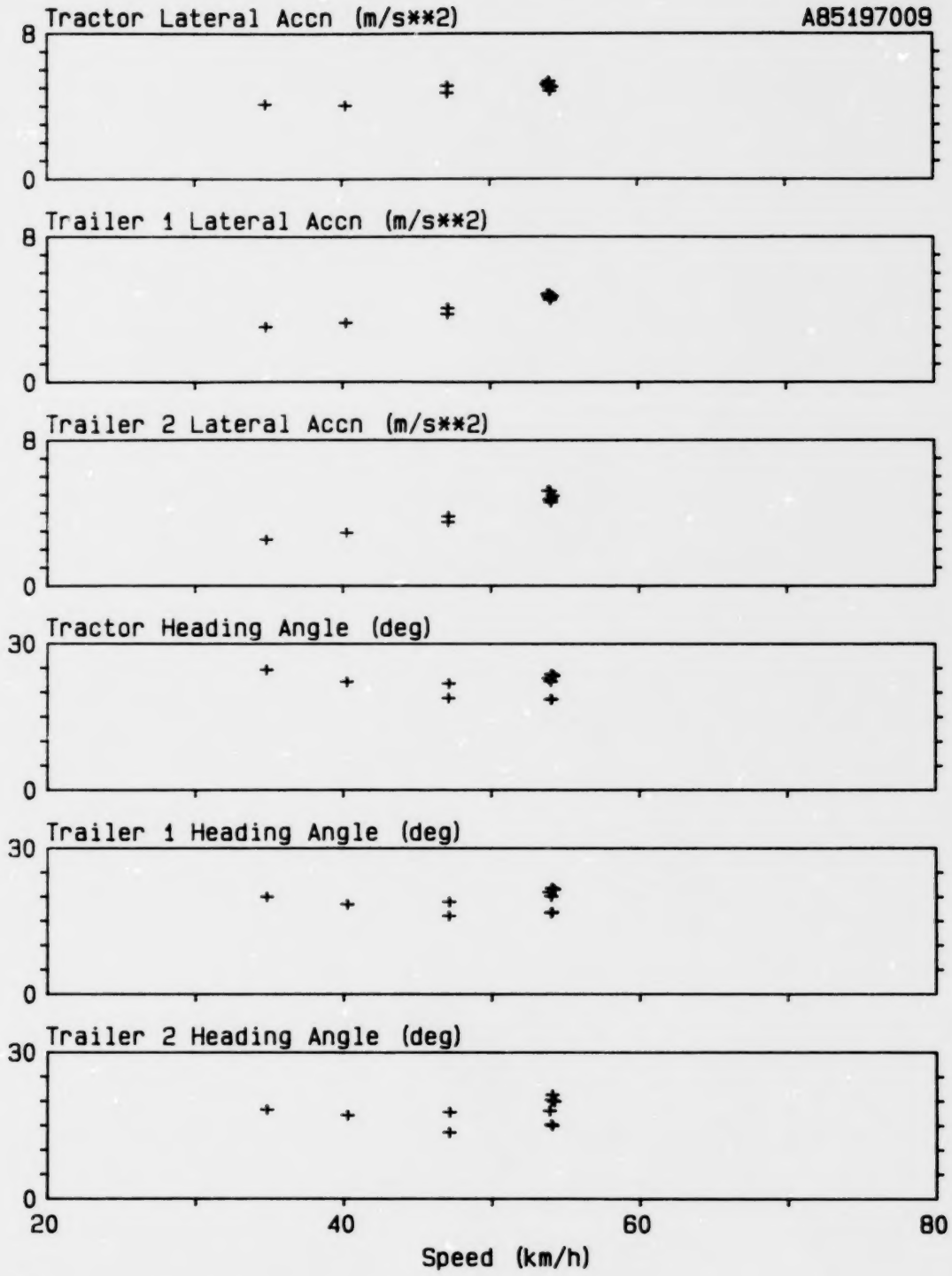


Figure 13/ B-Train Double, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed

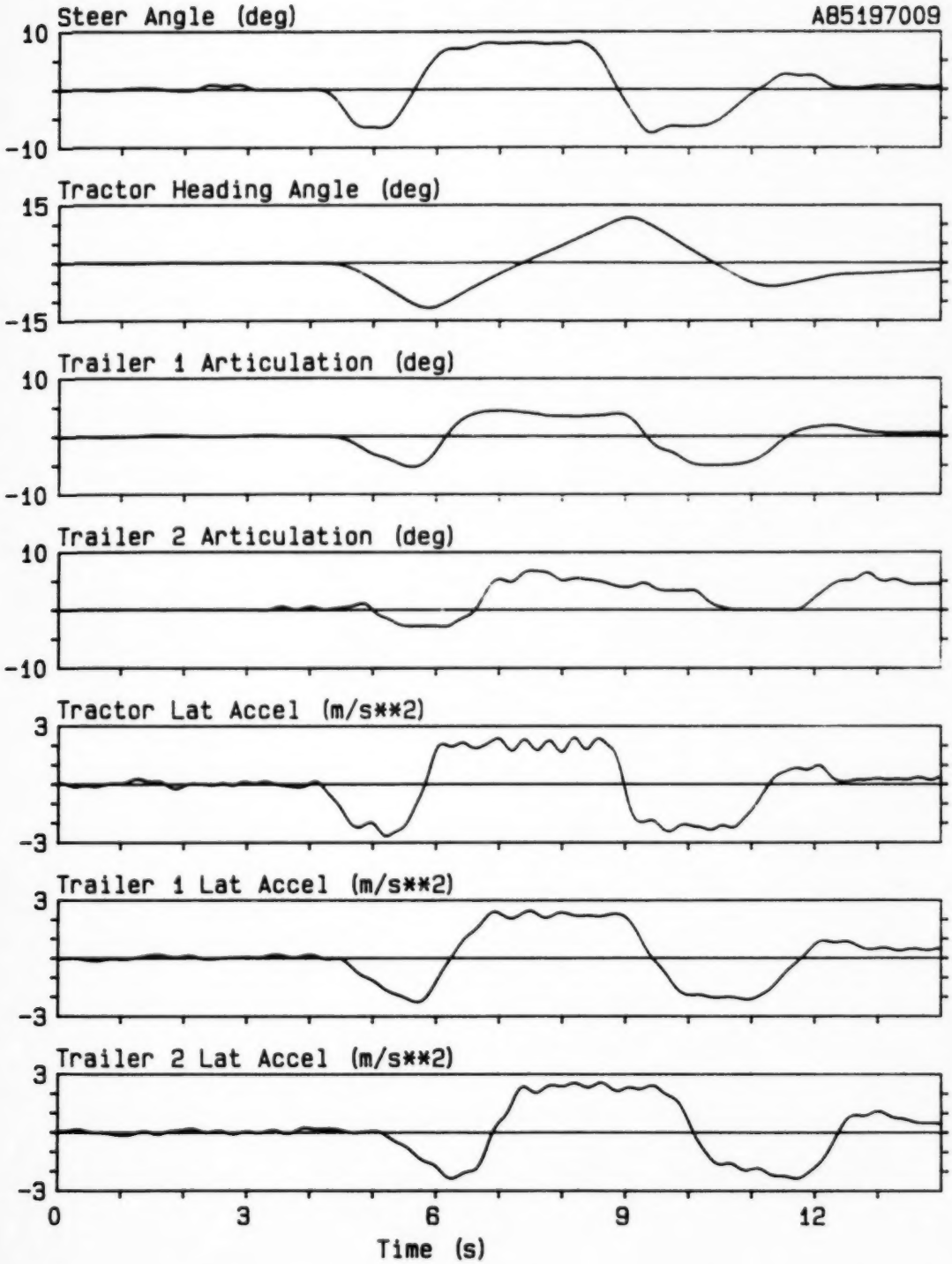


Figure 14/ B-Train Double,

Vehicle Response in Evasive Manoeuvre

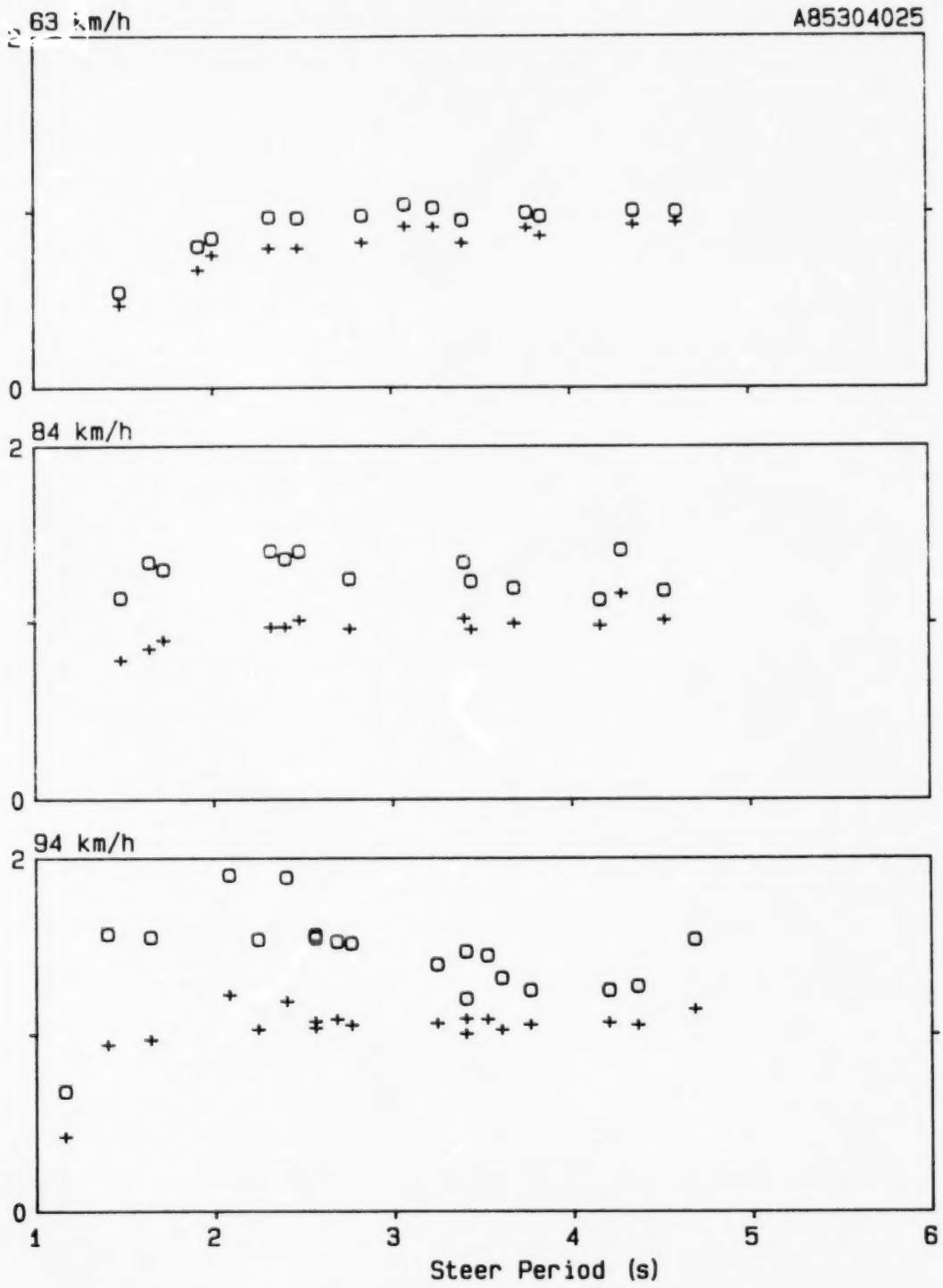


Figure 15/ B-Train Double,

Rearward Amplification of Lateral Acceleration

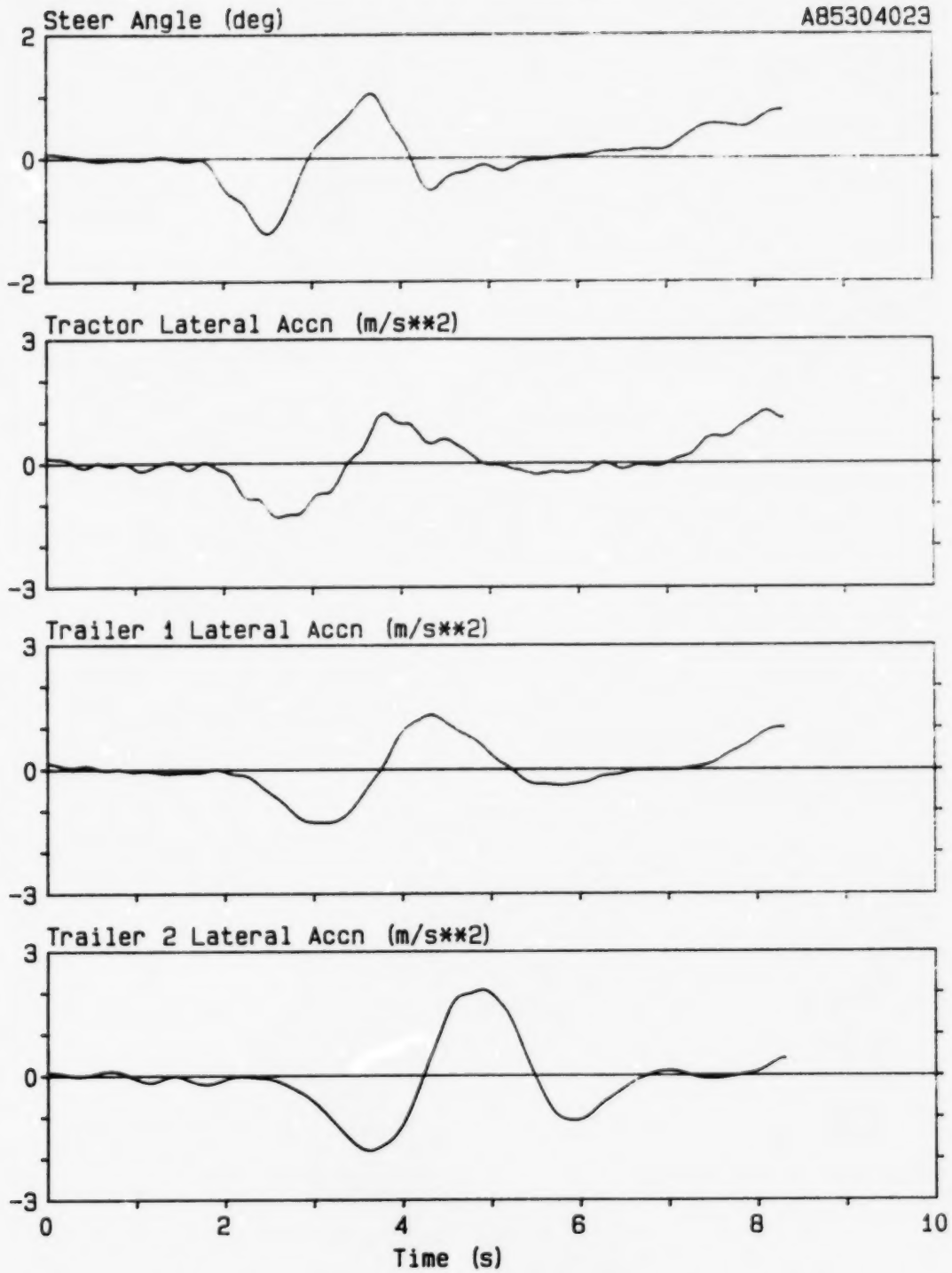


Figure 16/ B-Train Double, Sinusoidal Steer,
Vehicle Responses at 94 km/h

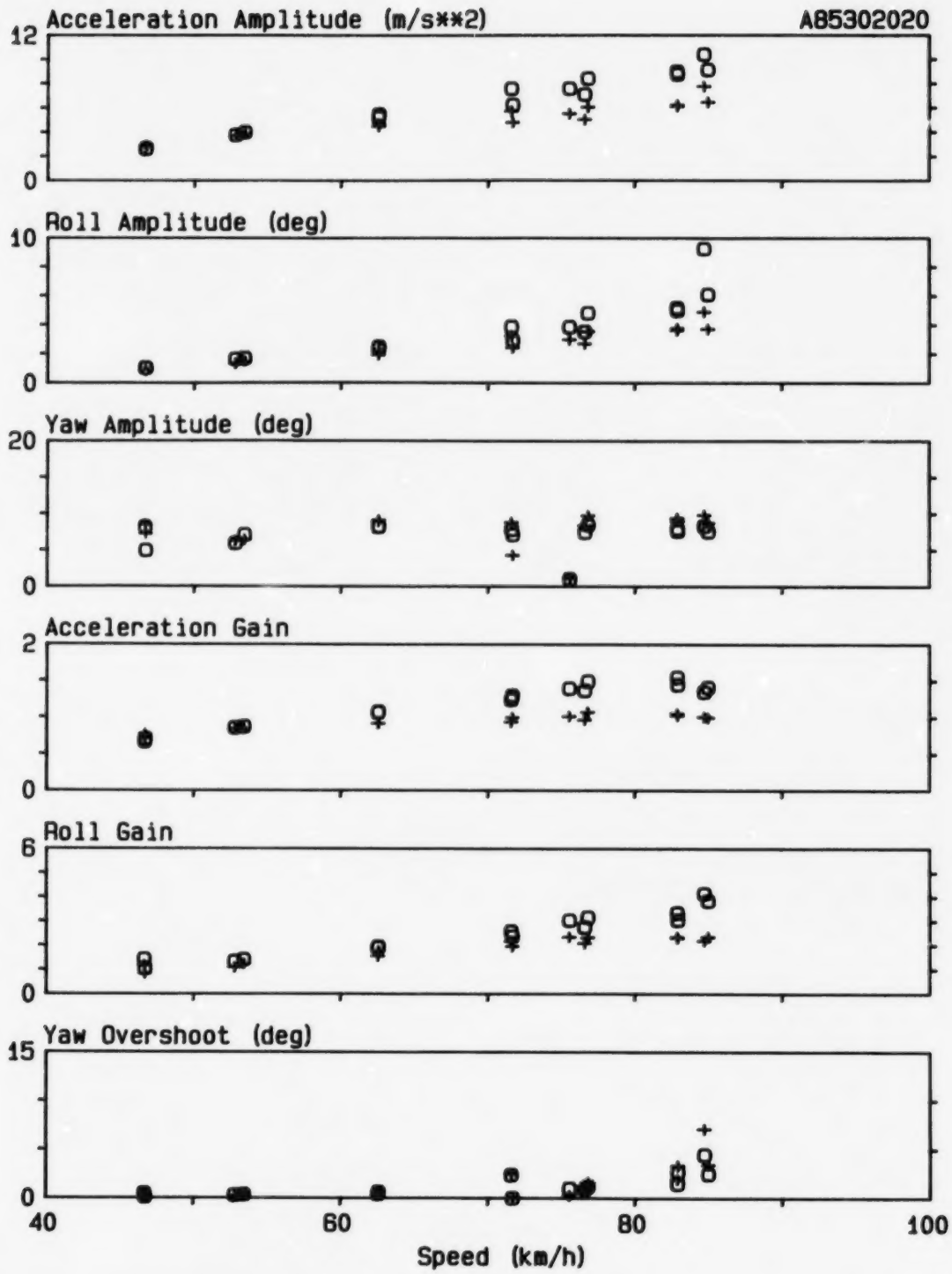


Figure 17/ B-Train Double, Lane Change,
Vehicle Responses vs Speed

Figure 18/ B-Train Double Making Lane Change

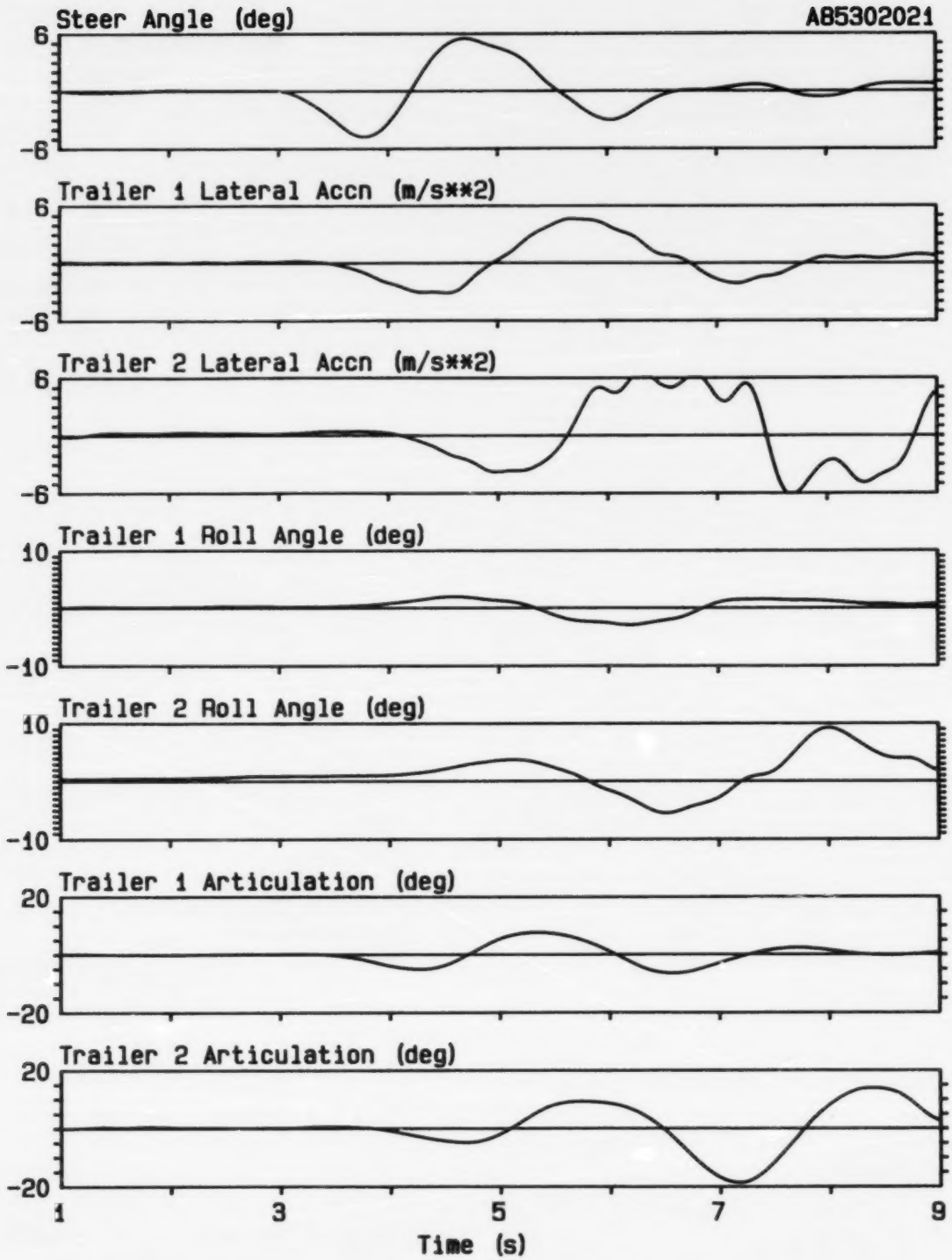


Figure 19/ B-Train Double, Lane Change,
Vehicle Responses at 85 km/h

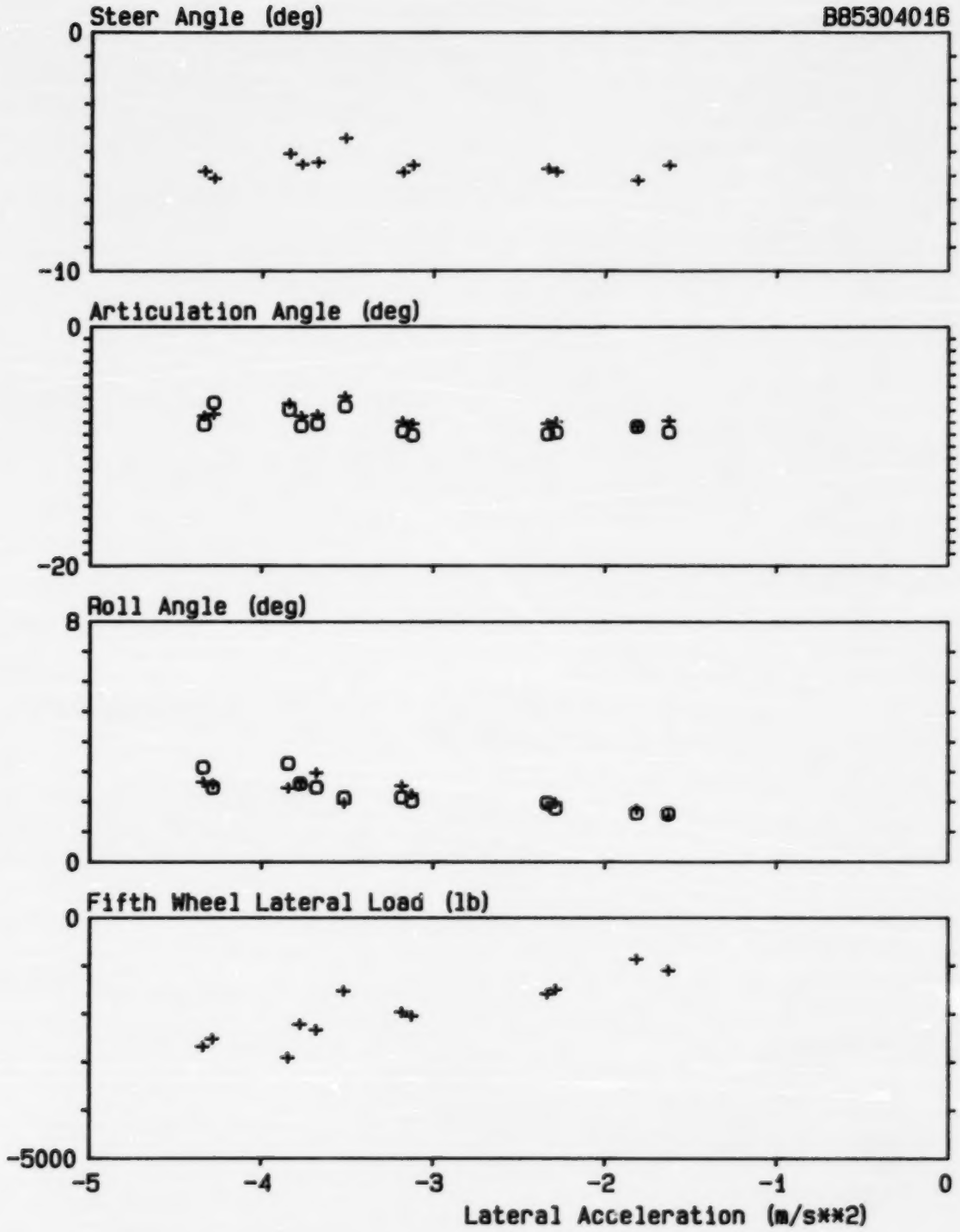


Figure 20/ B-Train Double, Steady Circular Turn,
Vehicle Responses vs Tractor Lateral Acceleration

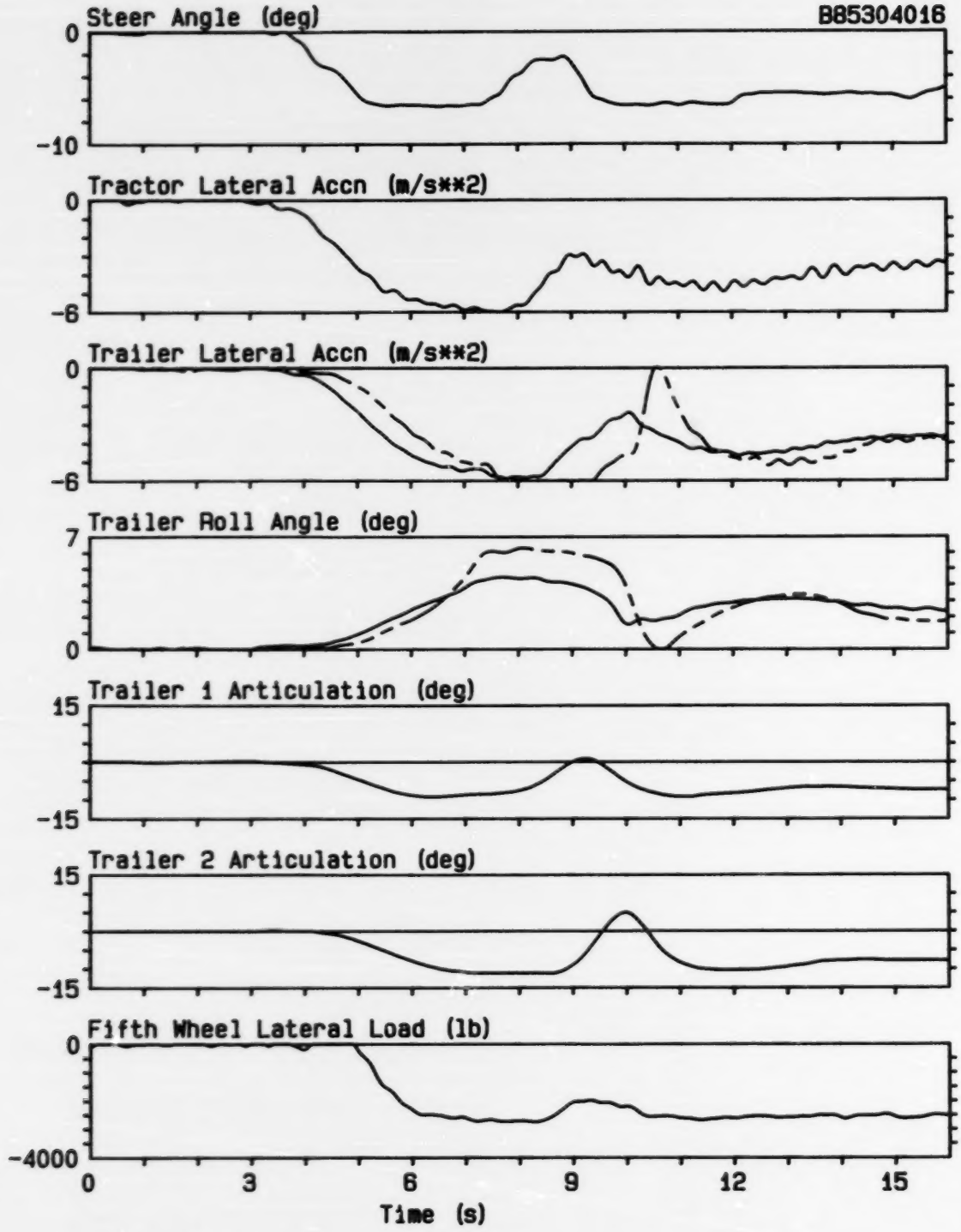


Figure 21/ B-Train Double, Steady Circular Turn, Vehicle Responses at 63 km/h

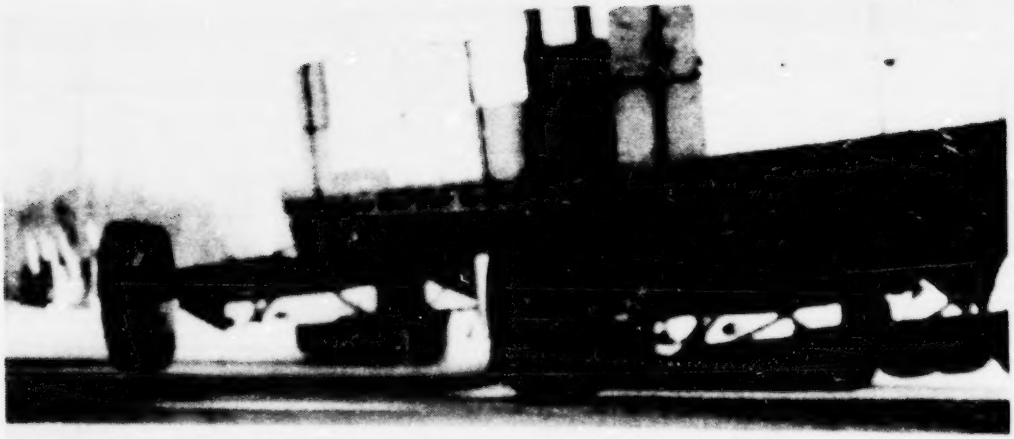


Figure 22/ B-Train Double Making Steady Circular Turn

Figure 23/ B-Train Double on Tilt Table